Using Scaleable Sensor Networks to Estimate Green Roof Stormwater Runoff in Remote Locations

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I. Brief history of greenroofs and definition

II. Houston Greenroof and scalable sensor networks

III. Preliminary results and discussion

IV. Future plans for Houston and beyond

I. A brief history of greenroofs

Gudbrandadal, Norway (2007)

…Analogous to 11th Century "Vikingsholm"

(Source: http://en.wikipedia.org/wiki/File:Heidal.jpg)

Berlin,
Germany

Rockefeller Center

(1936)

http://urbangreens.tumblr.com/

Intensive greenroofs

Waldspirale: Darmstadt, Germany

Christa Reuter Kunsthaus Wien

Extensive greenroofs

Ford Motors, Michigan

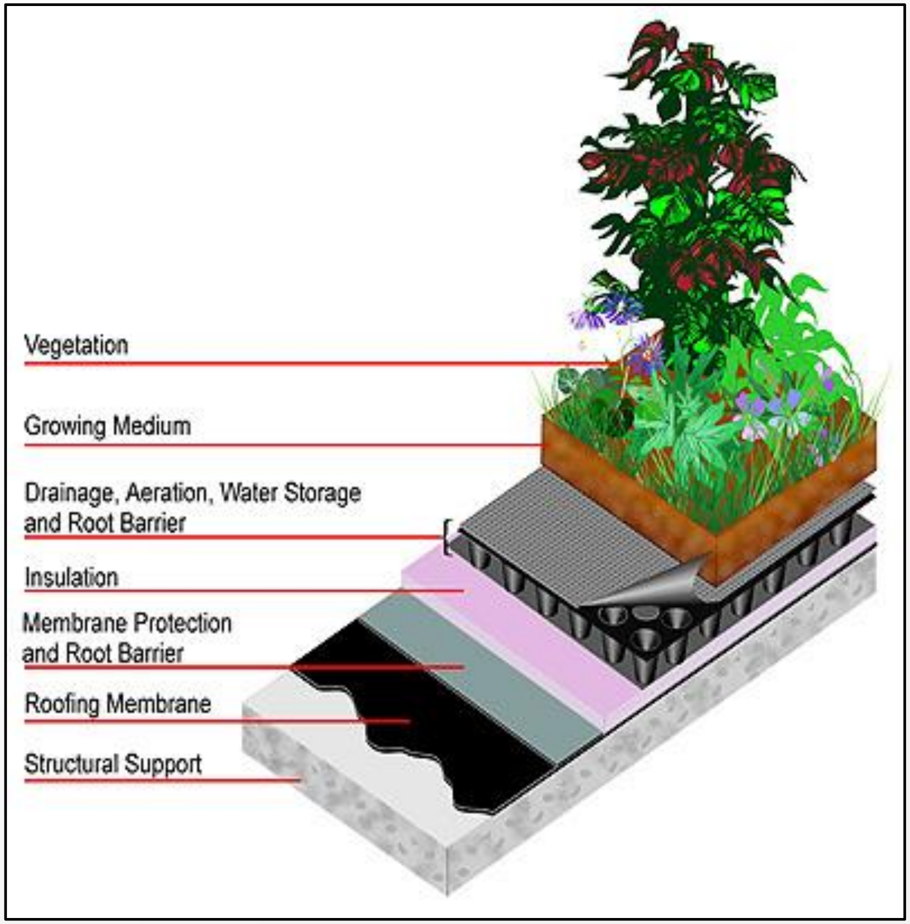
(www.greenroofs.org)

Table 1
Example soil thickness of intensive and extensive vegetated roofs as defined by different authors.

Intensive (mm)	Extensive (mm)	Reference
150–1200	50–150	Kosareo and Ries (2007)
>500	–	Köhler et al. (2002)
150–350	30–140	Mentens et al. (2006)
>100	<100	Wong et al. (2007)
>300	–	Bengtsson et al. (2005)
>100	20–100	Graham and Kim (2005)

(Berndtsson 2010)

How to define a greenroof?



http://www.princetonreview.com/green-honor-roll.aspx

http://www.toronto.ca/greenroofs/what.htm

II. “What Greenroofs do”

Provide Multiple ecosystem services

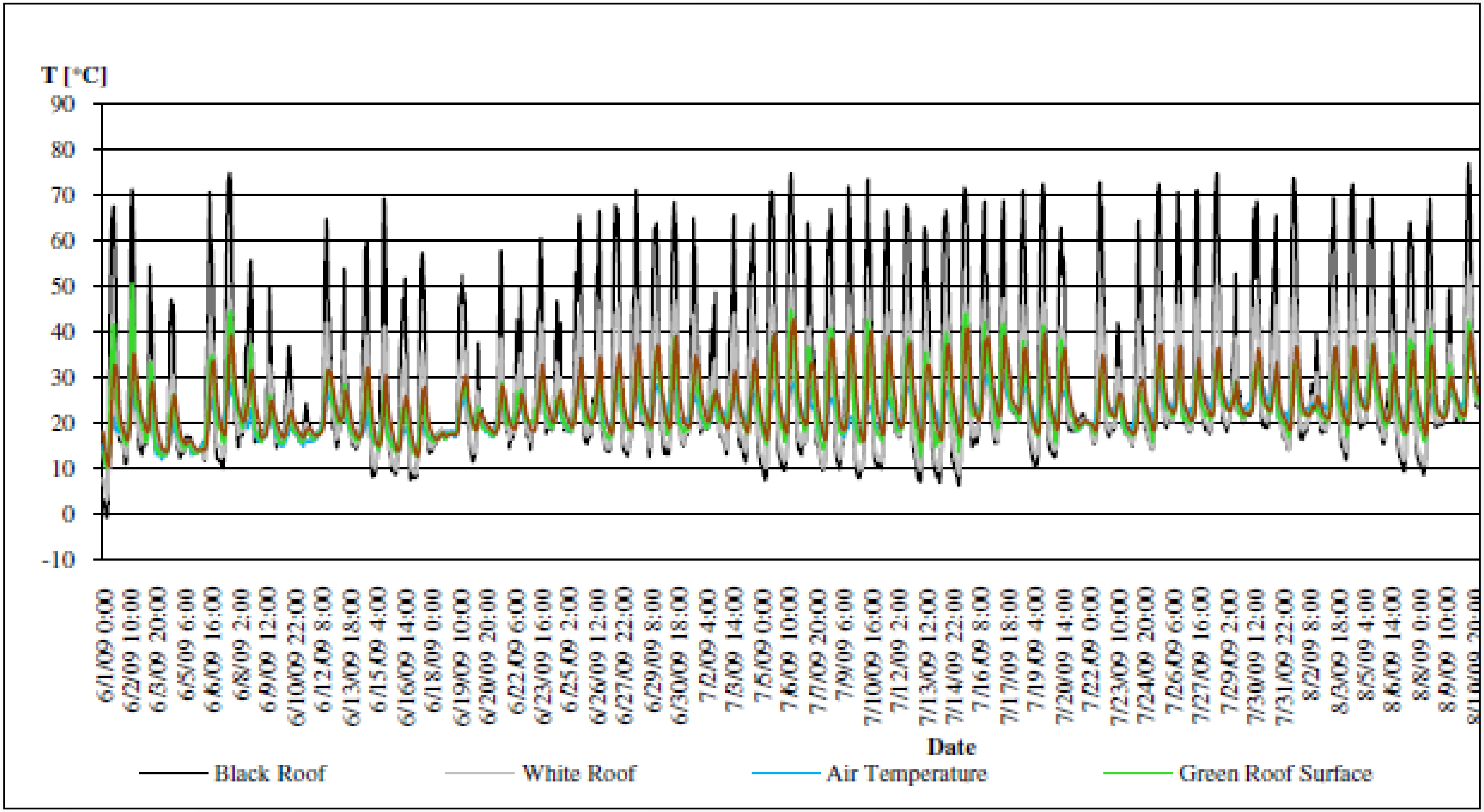
- Construction and maintenance
  (Ryerson University 2005)
- Habitat/Greenspace
  (Jones 2002, Brenneisen 2003)
- Air Quality
- Sound buffer
- Social benefits
- **Energy savings**
  (Saiz et al. 2006)
- **Stormwater management**

Queens botanical garden

http://www.nytimes.com/2004/09/16/garden/16BOTA.html

http://www.roofmeadow.com/case-studies/selected-case-studies/queens-botanical-garden-visitor-adminstration-building/

Greenroof temperature comparisons



Susca et al. 2011

Energy Savings of the Baseline Green Roof compared to the Conventional Roof

In order to establish a starting point for evaluating the building energy performance of a green roof the baseline green roof (case 5 in Table 2) is compared here with the conventional (albedo=0.3) membrane roof. Figure 4 shows the gas and electricity energy and cost savings per unit roof area for the baseline green roof compared to the conventional membrane roof.

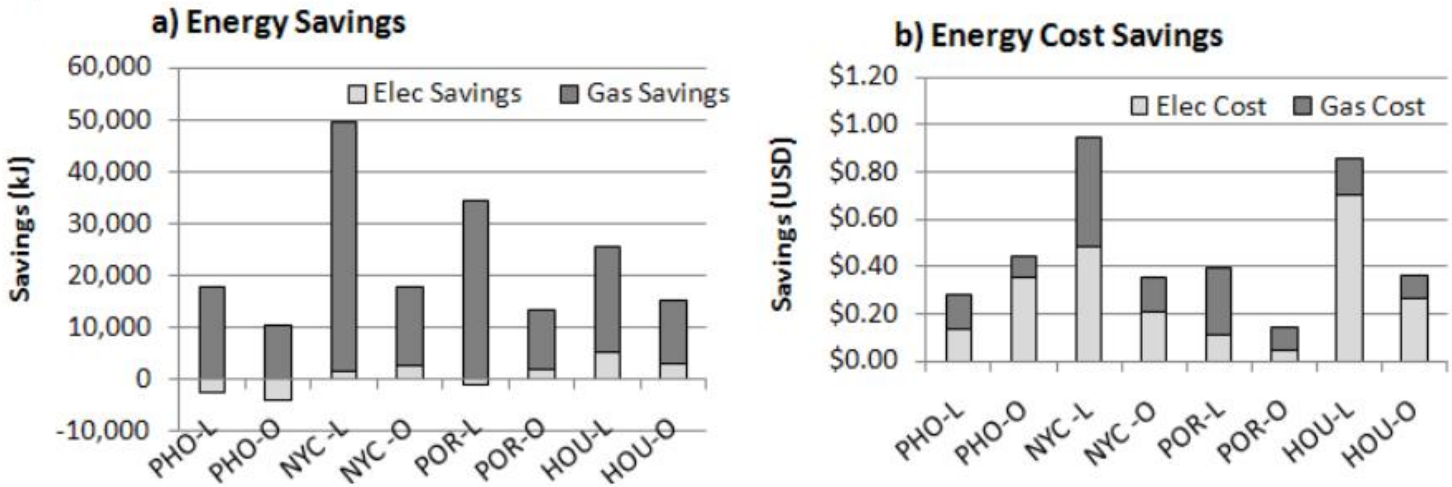
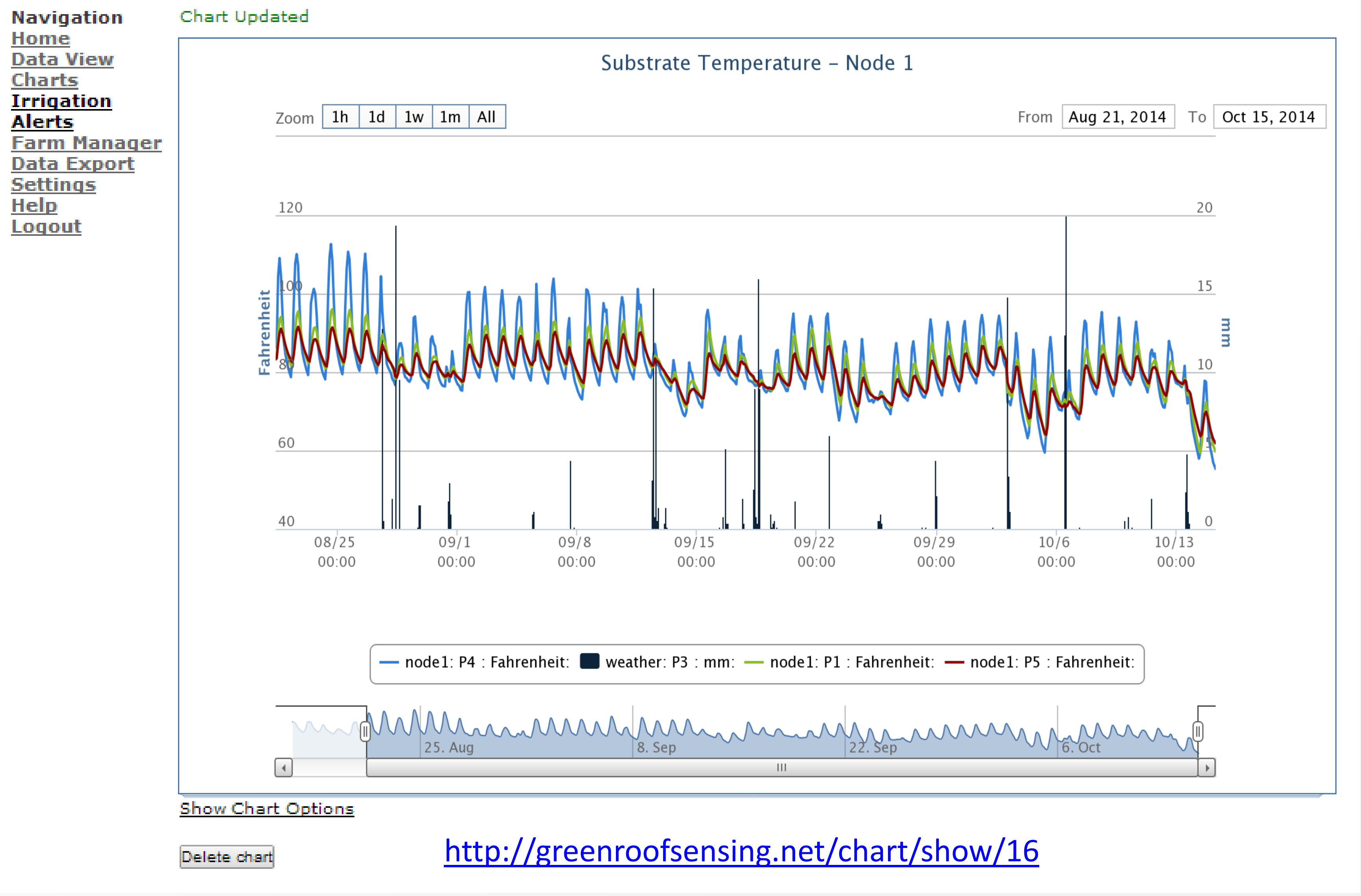


Figure 4. Electricity and gas savings of baseline green roof compared to conventional roof per square meter of roof area. Note: Office and lodging buildings have different roof-floor space ratios.

Sailor et al. 2012

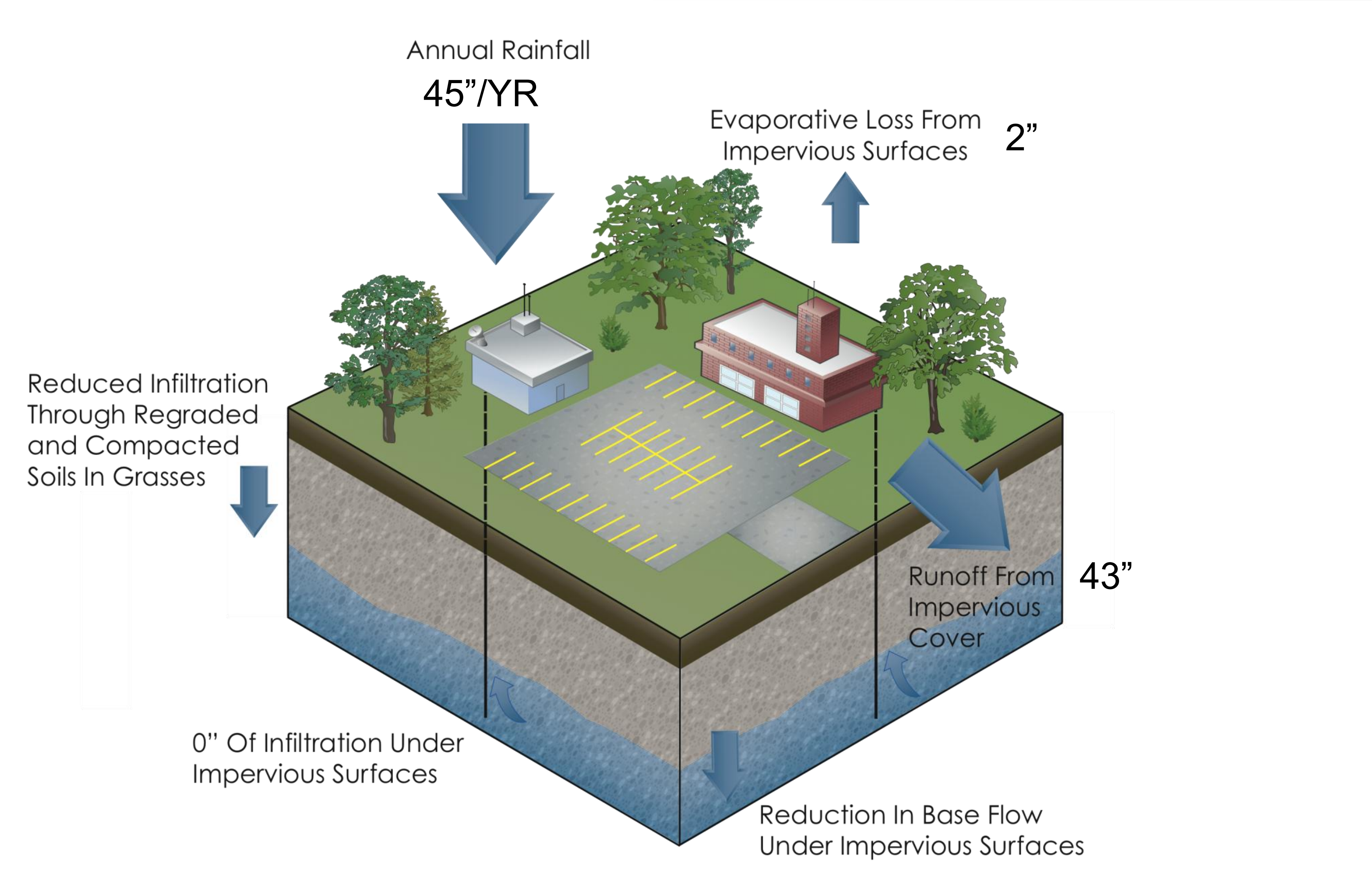
http://www.brikbase.org/sites/default/files/best3_sailor.pdf

NASA-JSC Building 12: Substrate Temperature



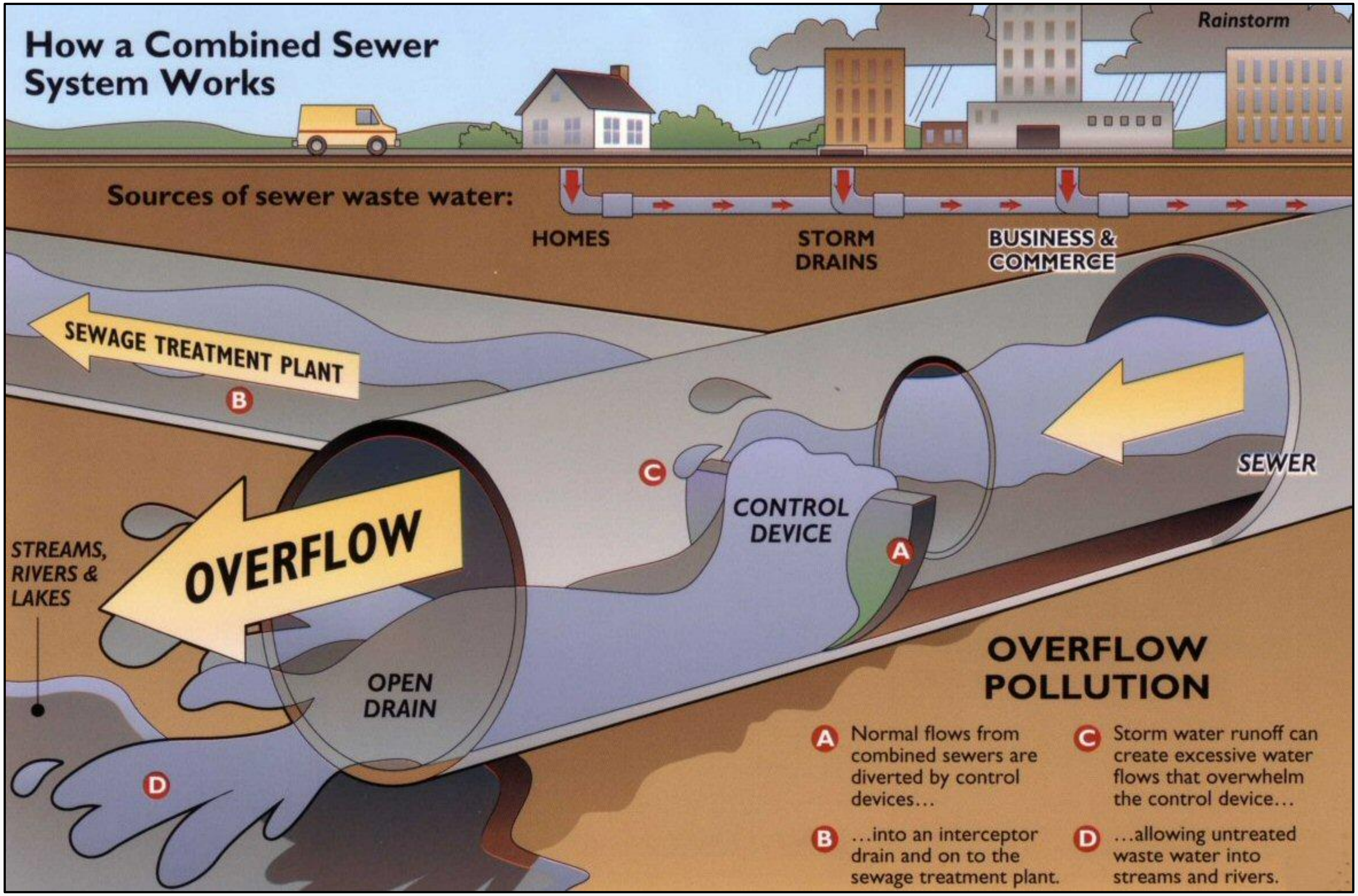
http://greenroofsensing.net/chart/show/16

Altered Water Cycle for an Average Year



Graphic courtesy of Meliora Environmental Design

Washington, DC



Economic Driver for Green Roof Installation – Washington DC, Impervious Area Charge

Beginning in FY 2011, all residential customers are assessed ERUs based upon the amount of impervious surface on their property and the following six-tier rate structure:

Impervious Area (Square Feet)	ERU	ERU Rate	Monthly Cost
100-600	0.6	$9.57	$5.74
700-2,000	1.0	$9.57	$9.57
2,100-3,000	2.4	$9.57	$22.97
3,100-7,000	3.8	$9.57	$36.37
7,100-11,000	8.6	$9.57	$82.30
11,100 and more (= 0.25 acres)	13.5	$9.57	$129.20

FY 2011 Rates from: http://www.dcwater.com/customercare/iab.cfm

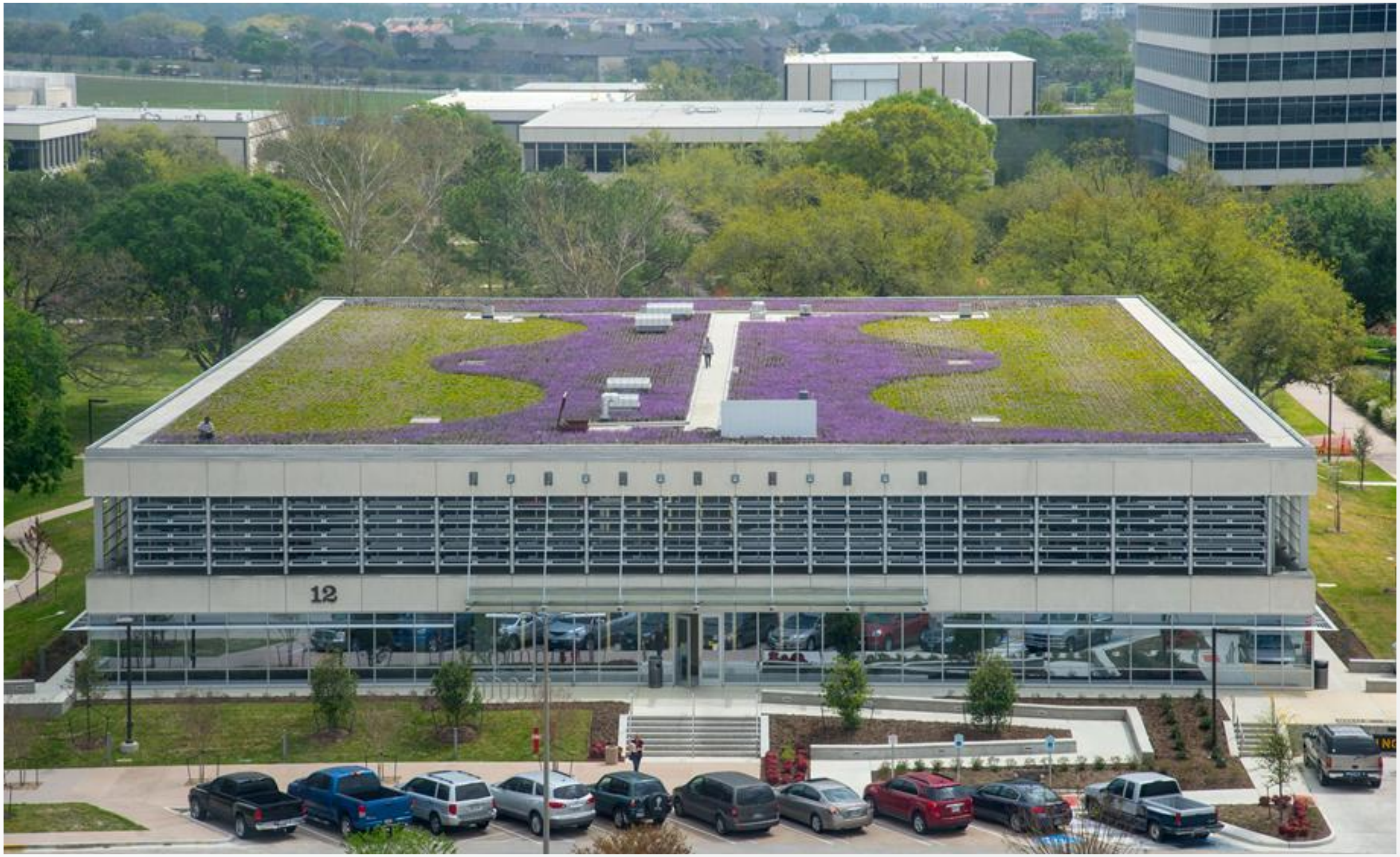
Economic Driver for Green Roof Installation – Washington DC, Impervious Area Charge

FY 2015 Rates (Effective 10/1/14) are $16.75 per ERU

Impervious Area (Square Feet)	ERU	ERU Rate	Monthly Cost	% Increase (from FY11)
100-600	0.6	$16.75	$10.05	
700-2,000	1.0	$16.75	$16.75	
2,100-3,000	2.4	$16.75	$40.20	
3,100-7,000	3.8	$16.75	$63.65	75.1%
7,100-11,000	8.6	$16.75	$144.05	
11,100 and more (= 0.25 acres)	13.5	$16.75	$226.13	

FY 2015 Rates from: http://www.dcwater.com/customercare/rates.cfm#currentrates

III. NASA-JSC Building 12 Green Roof



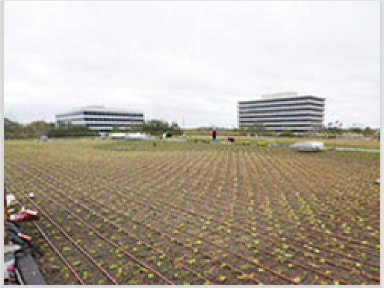
Feature

Text Size Tweet 7 Like 40 Pin it

Johnson Space Center Takes Green to a New Level: the Roof 03.13.12

Johnson Space Center team members have been observing the renovation of Building 12, one of the most visible of the ongoing construction projects at the center. But it's not just any construction. Building 12, which will house personnel from several mission support directorates, will be the first at JSC to have a green roof, also known as a garden or vegetative roof.

The revamped structure will have an open-office concept to improve workflow and day lighting. The building was designed to meet or exceed Leadership in Energy and Environmental Design (LEED) gold certification criteria set by the U.S. Green Building Council and will do that and more with the innovative green roofing system. Also, alternative energy sources will be relied on with the installation of photovoltaics and four vertical helix wind turbines.



Building 12 is the first at JSC to have a green roof, also known as a garden or vegetative roof. Photo credit: NASA

http://www.nasa.gov/centers/johnson/home/green_roof.html

“There are 1.2 million pounds of growing media (soil).”

“The total plant count is approximately 67,413.”

Dakota Mock Vervain

Rocky Point Ice Plant

Dwarf Pink Ruellia

Sedum mexicanum

Red Stonecrop

Sedum Rupestre ‘Angelina’

Greenroof monitoring challenges: how to monitor/demonstrate reduced runoff

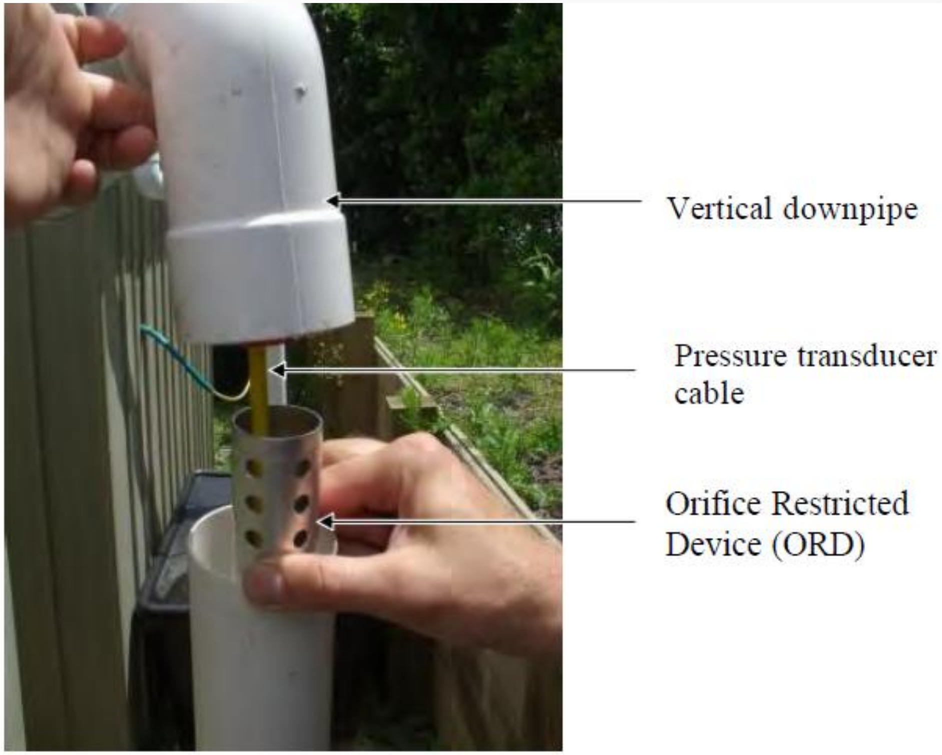


Figure 3. Tamaki mini-roof runoff collection systems

Greenroof monitoring solution:

Simple Water Balance Approach

i.e., A – B = C, where:

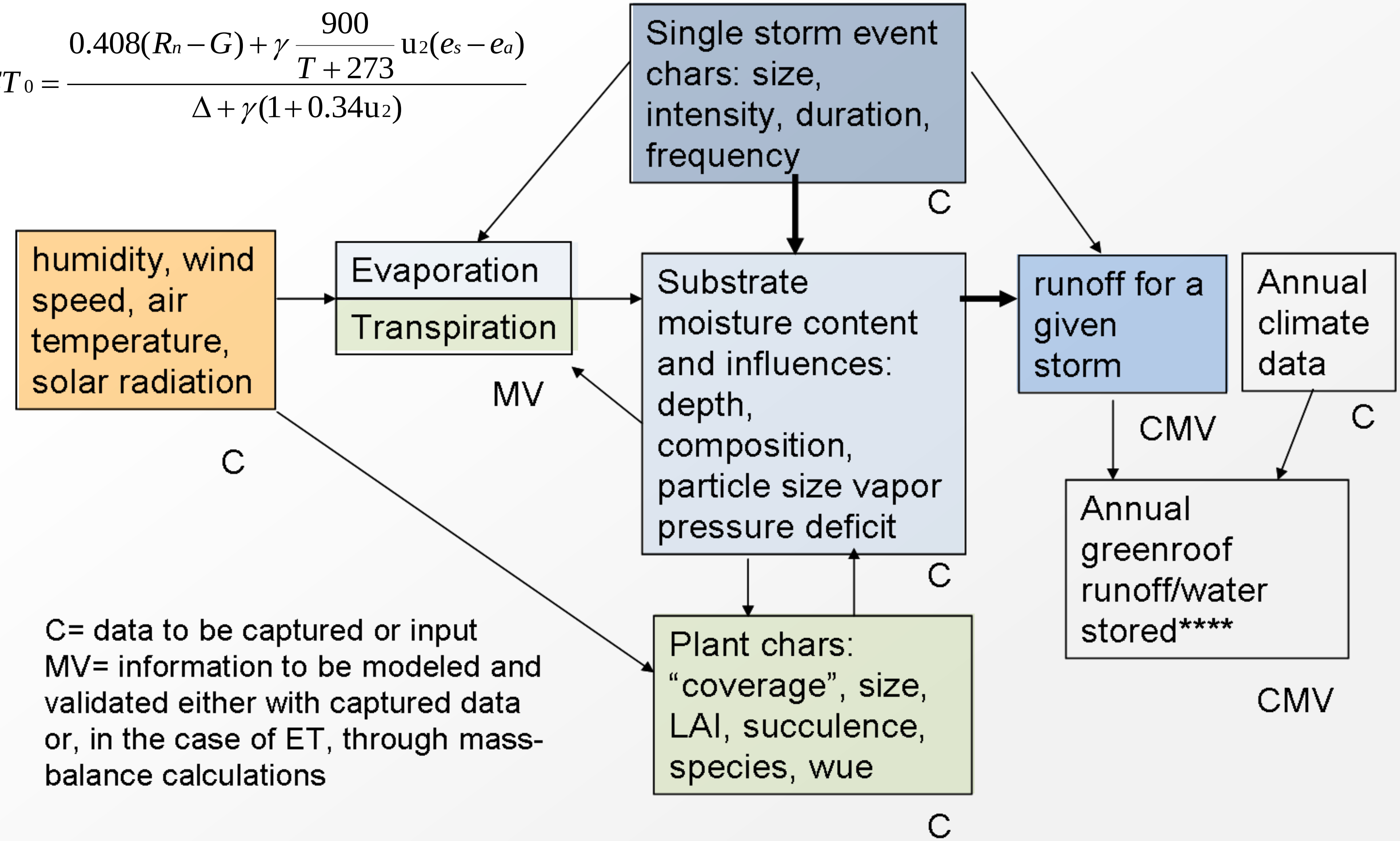
(A) (B) (C)

$$\boxed{\text{Rainfall (INPUT)}} \; - \; \boxed{\text{System removal } (\delta E_T / \delta t)} \; = \; \boxed{\text{Runoff}}$$

So -- if we know A and B at any given time,
we can predict C (= $\hat{C}$)

Modeling the Green Roof Water Cycle

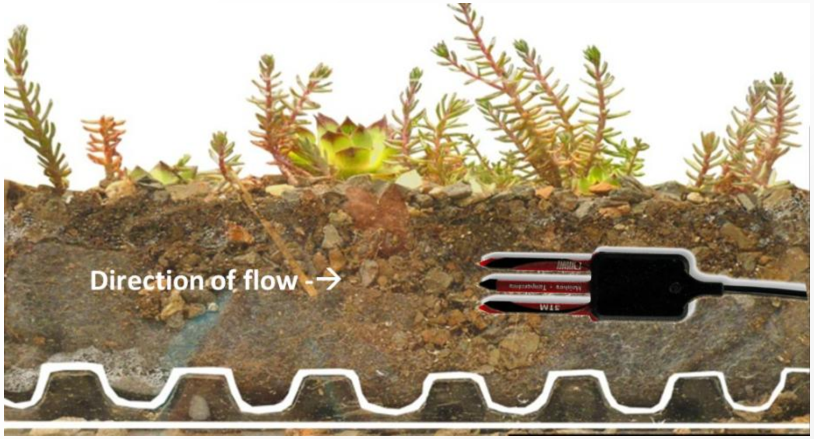
$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

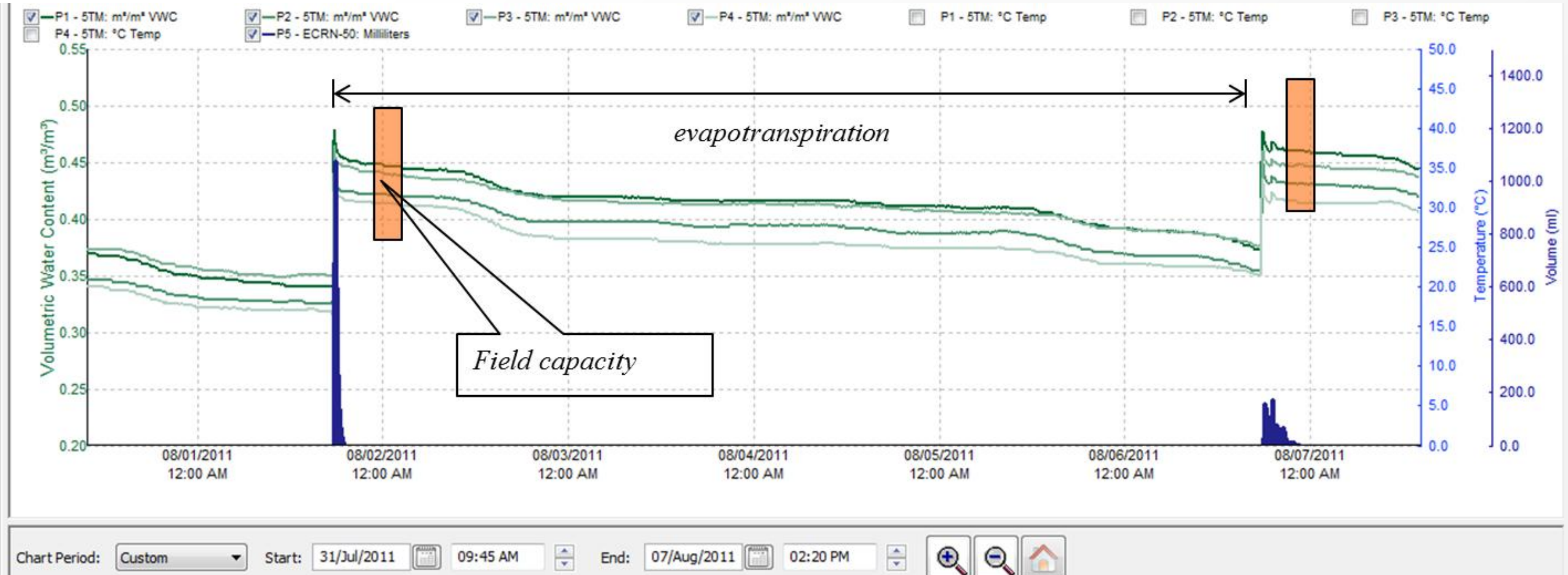


C= data to be captured or input
MV= information to be modeled and validated either with captured data or, in the case of ET, through mass-balance calculations

Olyssa Starry, PhD Dissertation 2013

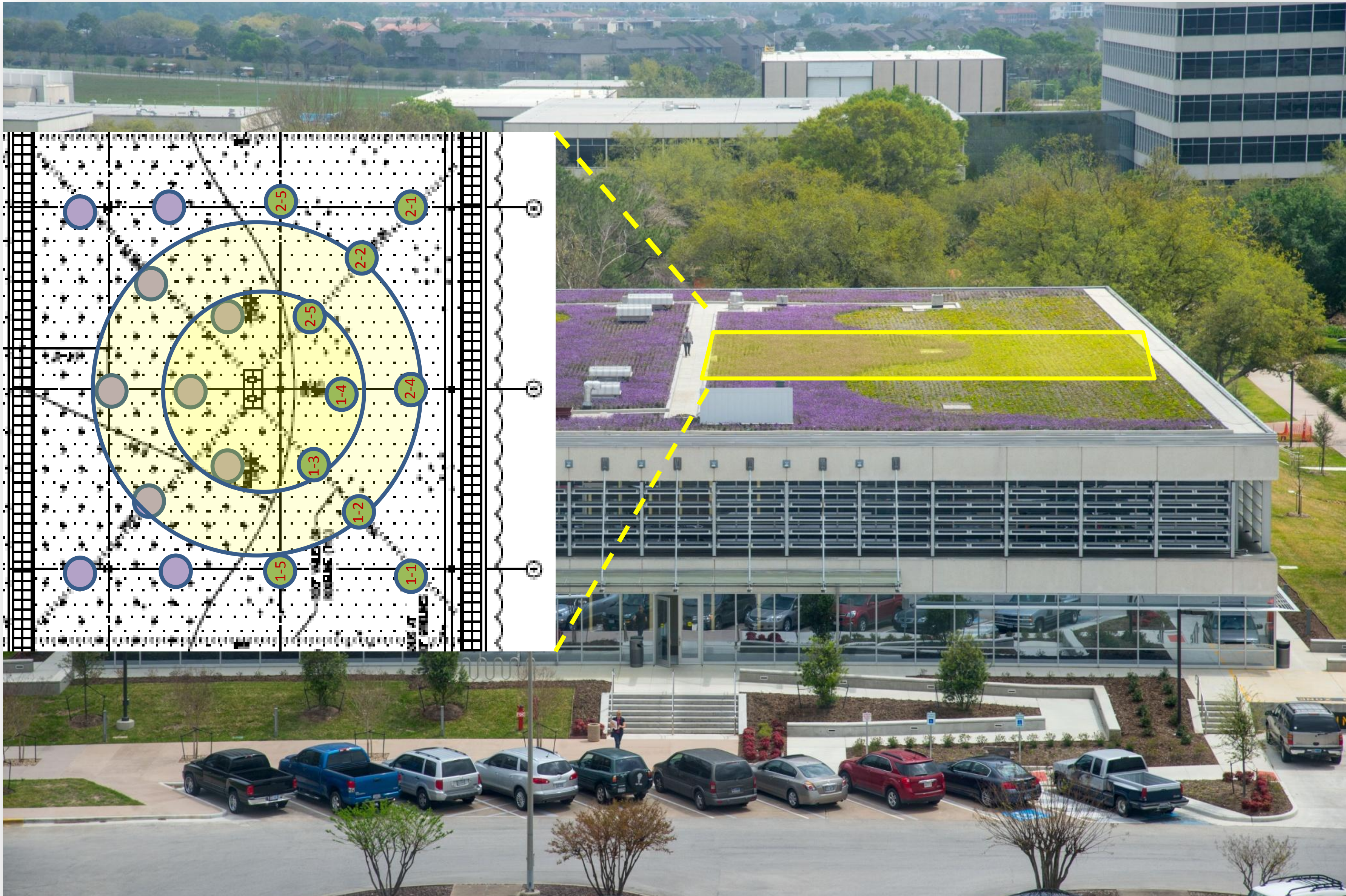
Measuring ET as change in substrate VWC





	P1 - m³/m³ VWC 5TM	P1 - °C Temp 5TM	P2 - m³/m³ VWC 5TM	P2 - °C Temp 5TM	P3 - m³/m³ VWC 5TM	P3 - °C Temp 5TM	P4 - m³/m³ VWC 5TM	P4 - °C Temp 5TM	P5 - Milliliters ECRN-50
Avg:	0.41	28.6	0.39	28.6	0.41	29.0	0.37	28.1	n/a
Min:	0.34	15.8	0.33	22.2	0.35	16.2	0.31	14.6	n/a
Max:	0.48	40.1	0.46	39.8	0.46	40.9	0.44	40.0	n/a
Total:	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6175
Events:	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	68

Building 12: EM50G Network Installed 02/14/14



Summary of Environmental Conditions: 2/2014-8/2014

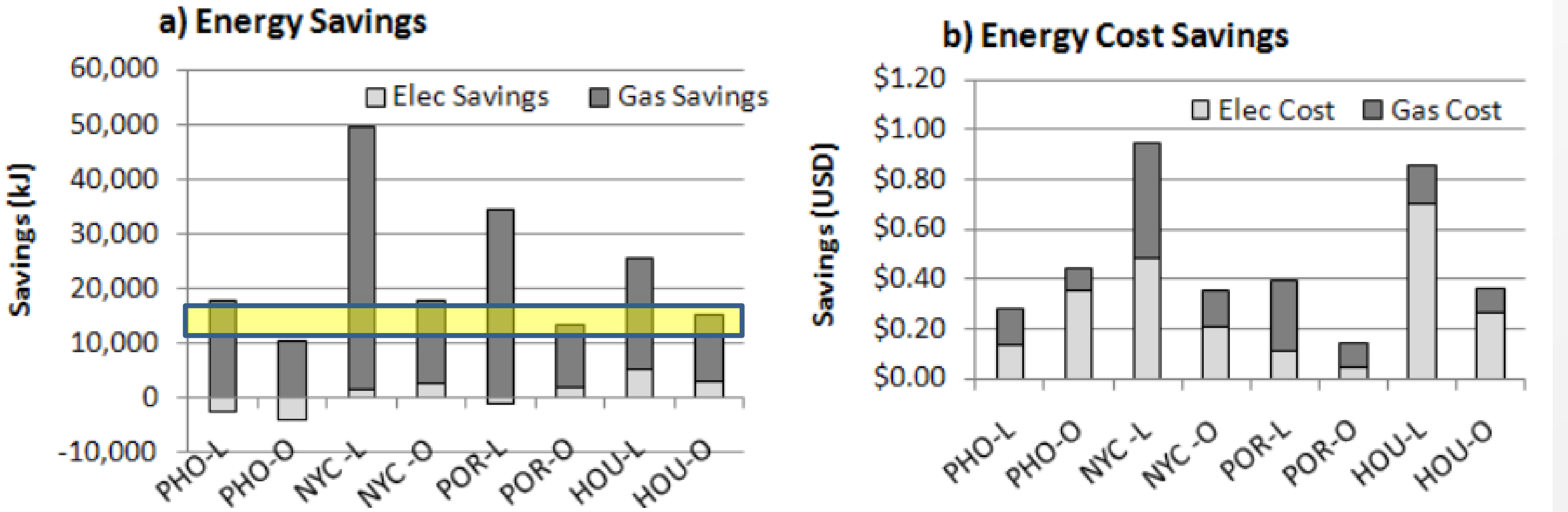
	Min	Max	Daily Average
Temperature (F)	28.76	98.24	73.06
Solar radiation –daily total (W/m^2)	0	1168.21	232.70
Relative humidity (%)	21.97	100+	78.22
Wind Speed (m/s)	0	7.042	1.54
Precip (mm)	0	69	N/A

Houston Case study from 2/2014-8/2014

Rainfall+ irrigation (INPUT)	–	System removal (δE_T / δt)	=	Runoff
497mm + X (461,000L)	–	**332mm** (308,000L)	=	165mm +Y (153,000L)

2.45 MJ per m^2 is able to **vaporize** 0.001 m or **1 mm of water**

Energy savings:



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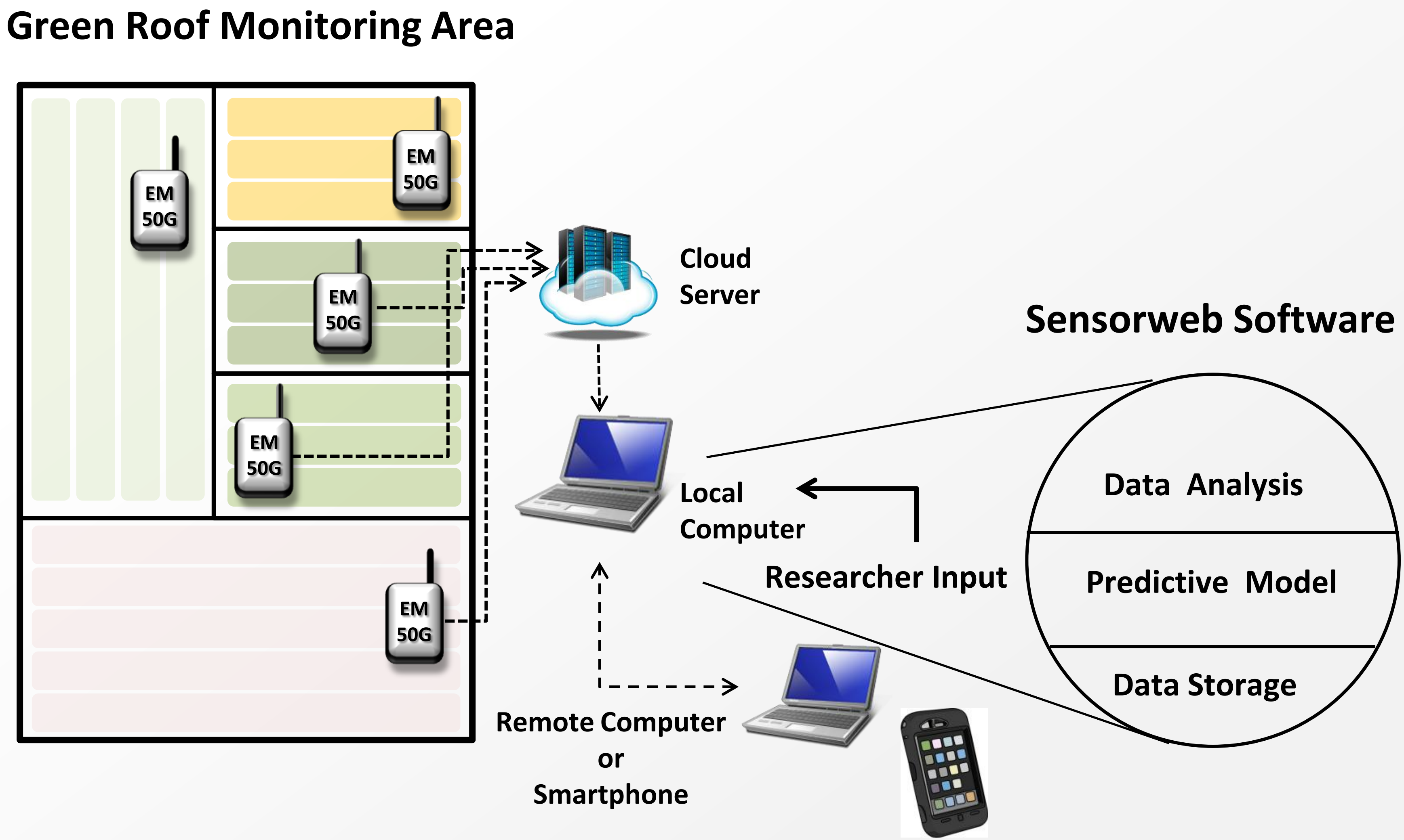
Sailor et al. 2012

http://www.brikbase.org/sites/default/files/best3_sailor.pdf

Sensor Networks – Monitoring Green Roofs



Smart Farms

SCRI-MINDS—Managing Irrigation and Nutrition via Distributed Sensing

saving water increasing efficiency reducing environmental impacts

USDA NIFA United States Department of Agriculture National Institute of Food and Agriculture

USDA-NIFA-SCRI Award no. 2009-51181-05768

NASA-JSC Green Roof Sensorweb

Oct 15 2014 09:32 EDT

Navigation
- Home
- Data View
- Charts
- Irrigation
- Alerts
- Farm Manager
- Data Export
- Settings
- Help
- Logout

Notes:

-Irrigation Turned on 3/31 at 11 am Delete

-Irrigation Adjustment Needed, Saturated in 2 days at 35 % Max. Use fewer days per week and less time Delete

-Batteries changed 5/12 Node 1 and node weather. Delete

-Sonic DS2 wind spd and dir out during rain. Reading Max values. Delete

-5/8/14 - Irrigation timer corected - new schedule 70% Max (42 min),2 x per day, on Su,M,W,Fr. Delete

-8/13/14 - MVB reported 5 soil sensors not reporting, DS ultrasonic not reporting speed or direction Delete

-8/18/14 - Dynamax maintenance complete, found 5 sensors loose and cables pulled from socket. Delete

-8/18 - reconnected cables, new batt, and tested all units passed.Rebooted weather node. Delete

Place mouse over location for details?

Add Note

Current Weather?:

1.0 m/s

0.0 mm/ml

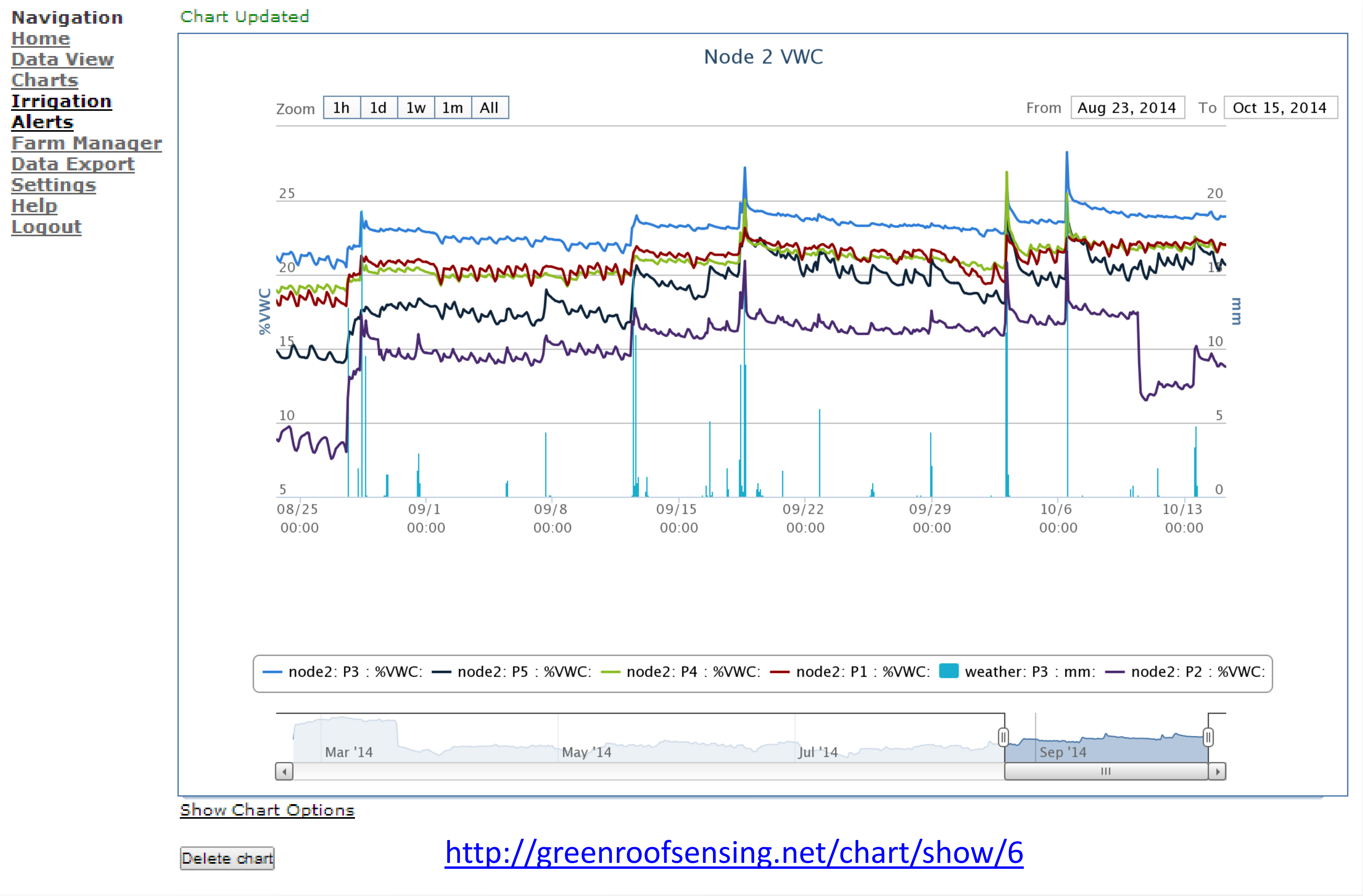
Legend?

	Min	Max
	30.0	50.0
	20.0	30.0
	10.0	20.0
	0.0	10.0
	Not in ranges above	

Measurements?
- Battery Life
- Daily Irrigation
- Electro-Conductivity (EC)
- PAR
- Sun Power
- Rainfall (Precipitation)
- Rainfall (Volume)
- Soil Moisture (%VWC)
- Temperature (Fahrenheit)

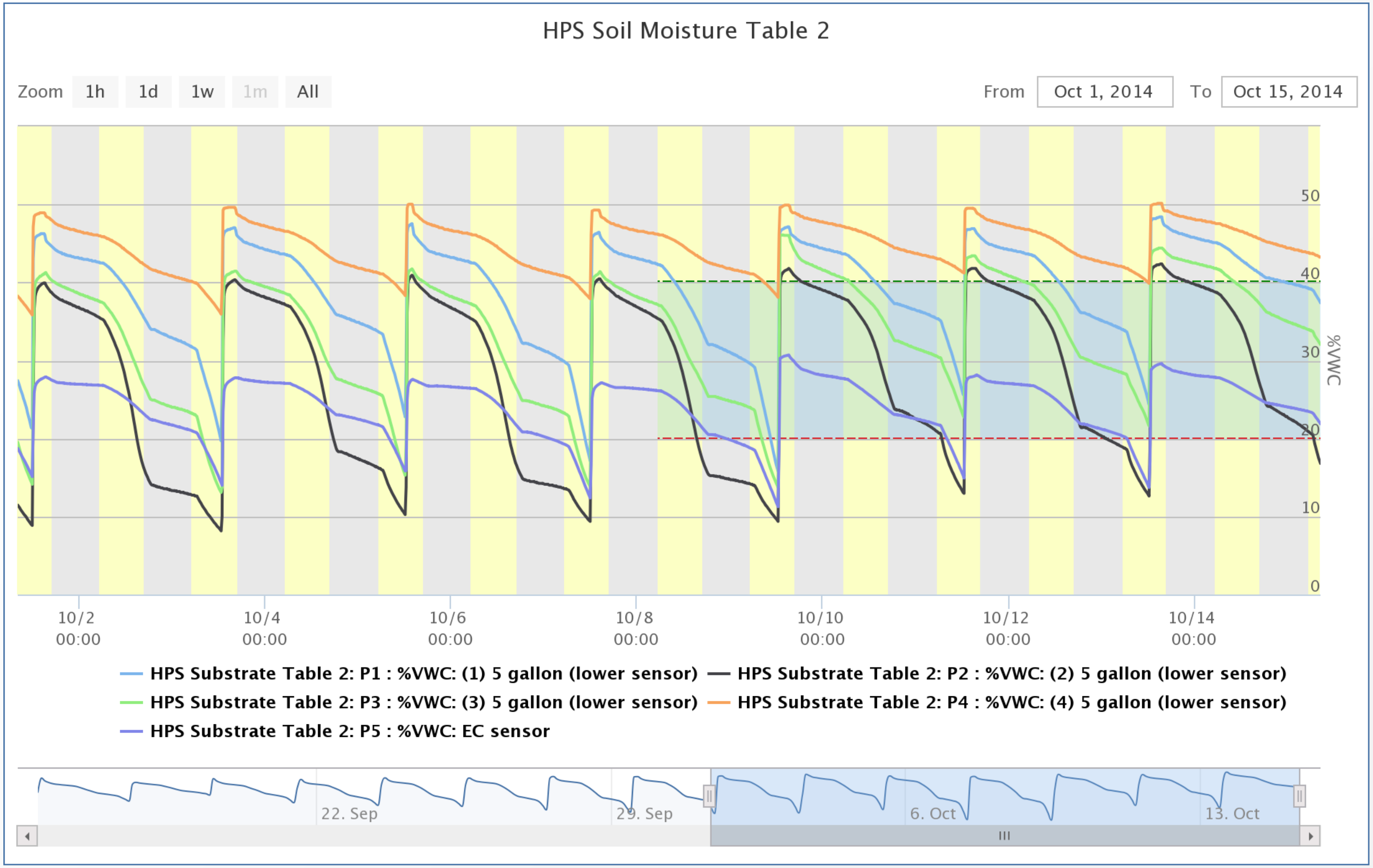
http://greenroofsensing.net

NASA-JSC Building 12: Irrigation and Rainfall



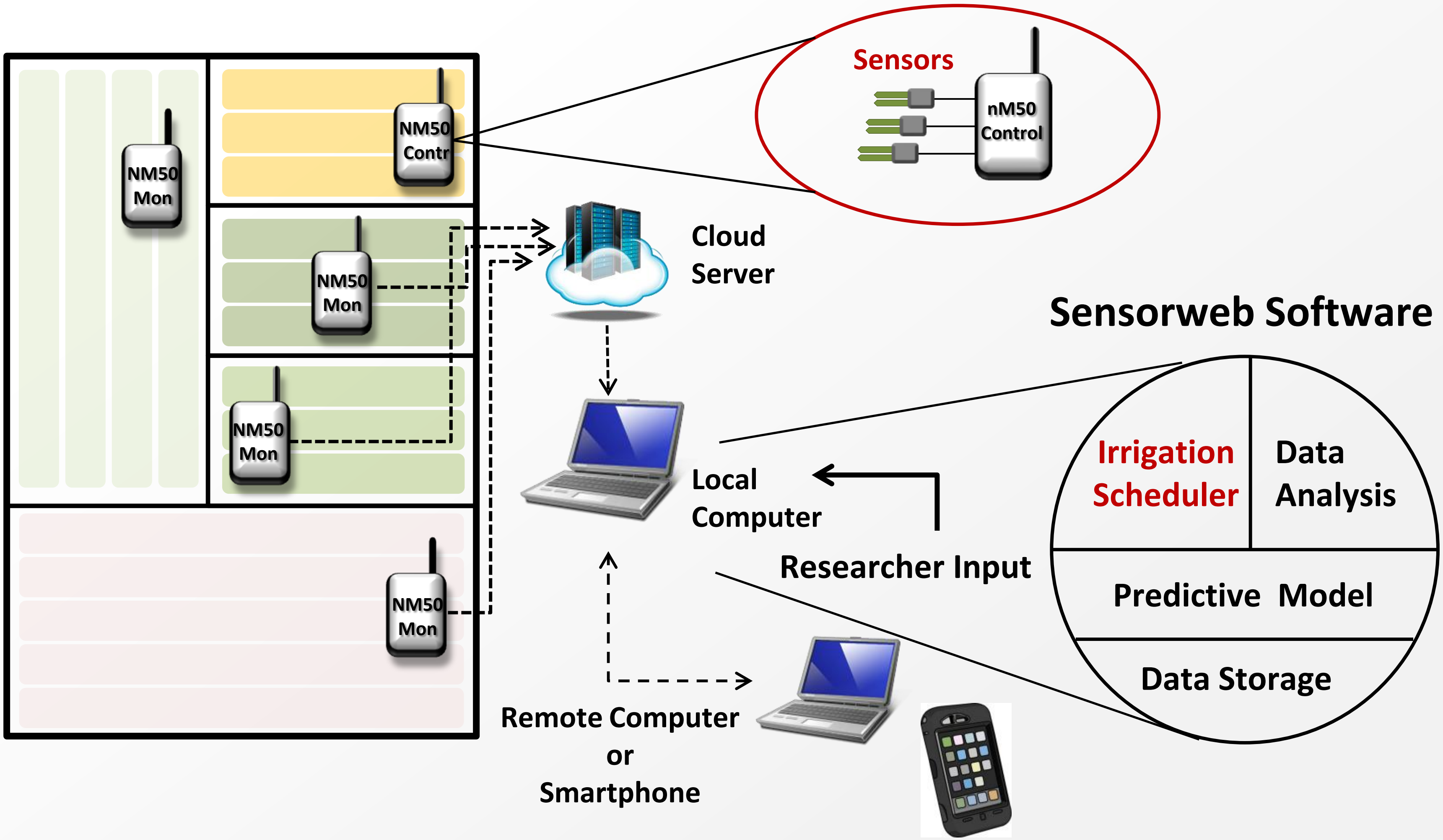
http://greenroofsensing.net/chart/show/6

Manually Controlled (time-based) Irrigation

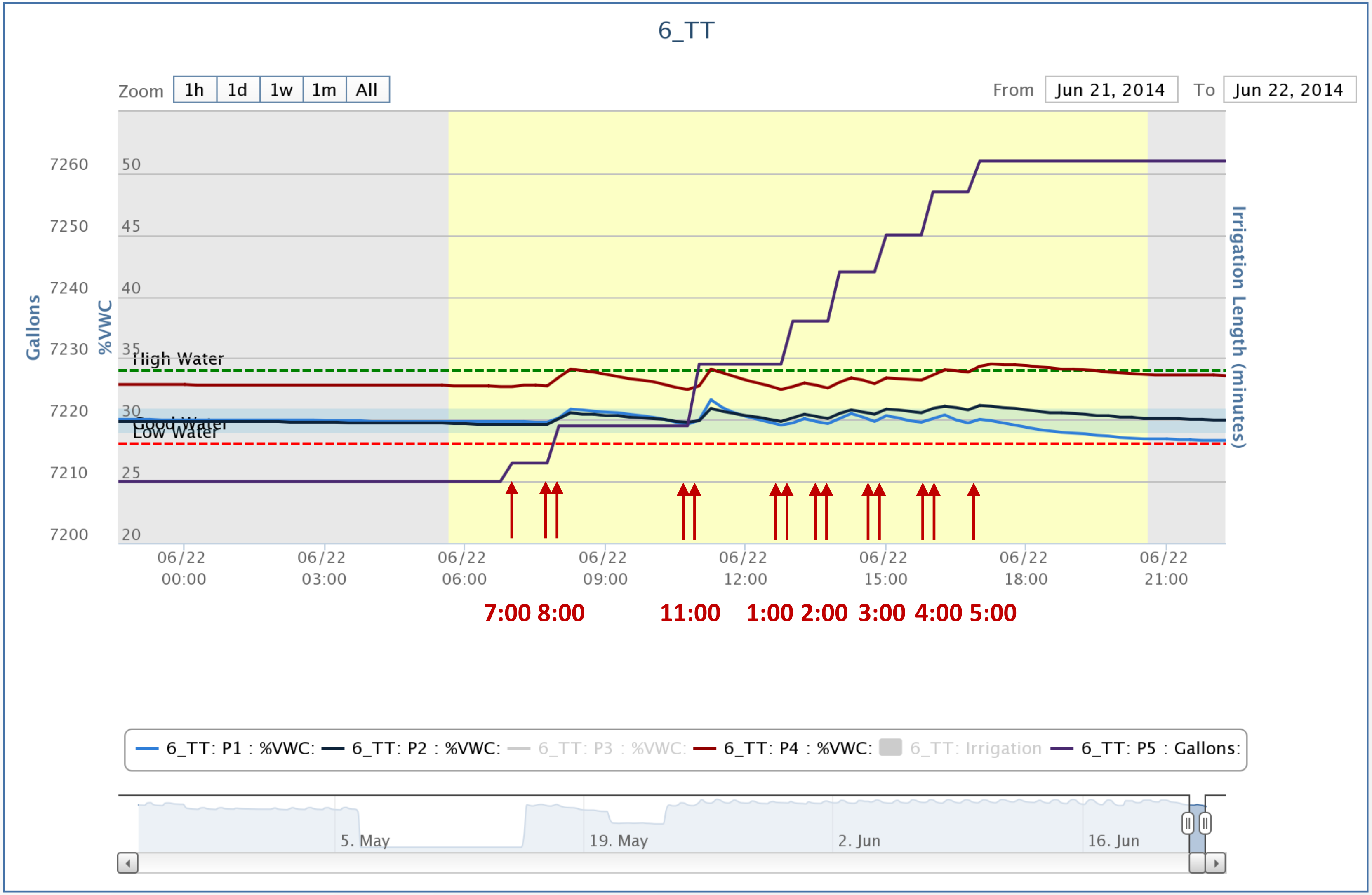


Sensor Network – Irrigation Control

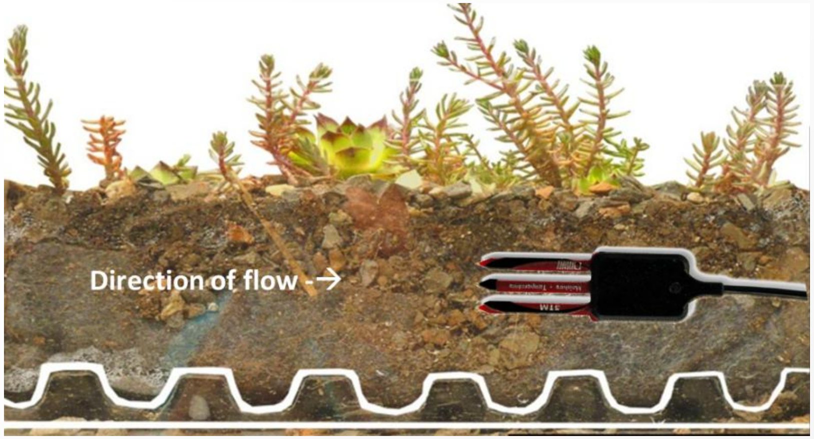
Green Roof Monitoring Area



Sensor-Controlled (set-point) Irrigation



Measuring ET as change in substrate VWC



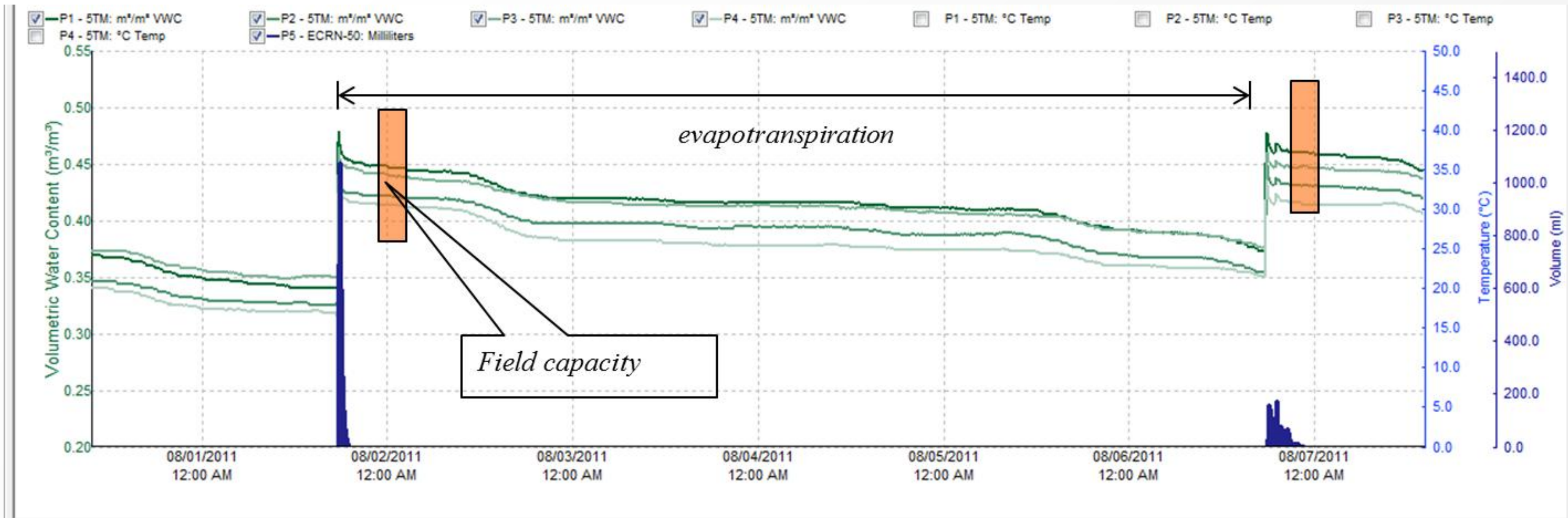


Chart Period: Custom Start: 31/Jul/2011 09:45 AM End: 07/Aug/2011 02:20 PM

	P1 - m³/m³ VWC 5TM	P1 - °C Temp 5TM	P2 - m³/m³ VWC 5TM	P2 - °C Temp 5TM	P3 - m³/m³ VWC 5TM	P3 - °C Temp 5TM	P4 - m³/m³ VWC 5TM	P4 - °C Temp 5TM	P5 - Milliliters ECRN-50
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Total:	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6175
Events:	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	68

Non-Irrigated Green Roof Scenario

Current Retention Efficiency: 40 - 80%

Carter and Rasmussen, 2007

Sensor Network Irrigation Control

Precision irrigation control on green roofs will:

a) Increase our ability to support more drought tolerant (C3) plants ⇧ *Increase Diversity*

b) Maintain plant heath, coverage and reduce maintenance ⇩ *Decrease Cost*

c) Increase stormwater removal between rain events
⇧ *Increase Green roof Efficiency*
⇧ *Total Stormwater Capacity*

Irrigated Green Roof Scenario

Increased Retention Efficiency: 60 - 90%?

Sensor Network Utility, Return on Investment

Sensor networks can be used to quantify and verify runoff and efficiency, ultimately by using a predictive stormwater runoff model

In Washington, DC, verification of storm water reductions will allow for trading water credits

The stormwater retention trading program will buy ***proven stormwater reductions*** currently trading at $2.95 per gallon for the first 50,000 ft^2, with a ceiling price of $3.50 per gallon [http://ddoe.dc.gov/src]

Houston Case study: Future goals

- Measure irrigation to better quantify inputs
- Use historical weather data to predict greenroof ET
- Optimize irrigation to maintain plants as well as to maximize cooling benefits

Near and Long-term Programmatic Goals

- Implement Sensor-based Irrigation
- Refine and revise the stormwater model
- Collect additional data:
  Runoff, air quality, biodiversity, wind speed (!)
- Cross-city, regional (metadata) comparisons
- Integrate Sensorweb into educational and outreach activities

Acknowledgements

NASA

http://www.nasa.gov/agency/sustainability

NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Leading clean energy innovation
U.S. DEPARTMENT OF ENERGY

http://www.nrel.gov

DYNAMAX

http://www.dynamax.com

Smart Farms
SCRI-MINDS—Managing Irrigation and Nutrition via Distributed Sensing
saving water increasing efficiency reducing environmental impacts

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National Institute of Food and Agriculture
USDA-NIFA-SCRI Award no. 2009-51181-05768

http://smart-farms.net

Questions?

http://www.greenfudge.org/2009/10/17/green-roof-technology-breathes-new-life-to-the-urban-jungle/

For more info visit: http://urbansod.blogspot.com

Contact:
ostarry@pdx.edu